Jet Propulsion Laboratory
California Institute of Technology

DIRECTED ENERGY PROPULSION FOR INTERSTELLAR PRECURSOR MISSIONS

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Jet Propulsion Laboratory, California Institute of Technology
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Pre-Decisional Mission Concept

Dawn was great but…

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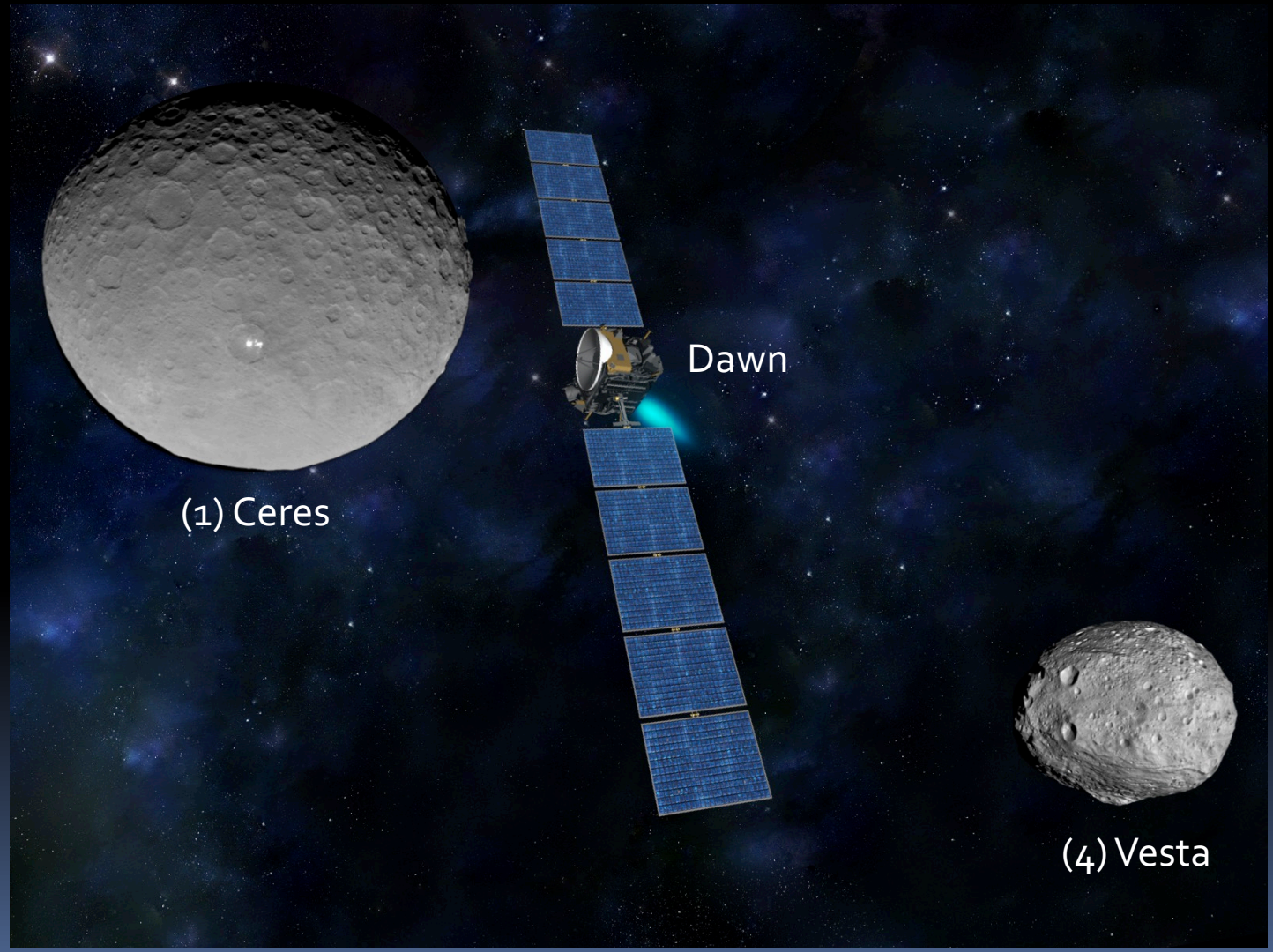
- The ion propulsion system on Dawn provided a record ΔV to the spacecraft of 11.5 km/s (25,900 mph, using just 60 gallons of fuel)
- But Dawn "only" went to ~3 AU
  - What if you wanted to go to Pluto at ~40 AU?
  - Or the solar gravity lens location at > 550 AU?
- You would have to go faster, *a lot faster*
  - We want ΔV's that are 10x higher than Dawn's, i.e., 100 to 200 km/s



How to Go Fast

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- Going fast takes a lot of energy: $E = \frac{1}{2} mv^2$
- Going 10x faster takes 100x the energy

100 km/s takes ~1000x
the energy density of TNT

How to Go Fast

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California Institute of Technology

- Going fast takes a lot of energy: $E = \frac{1}{2} mv^2$
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- How do you get that energy?
  1. You can carry it with you
     - ~~Chemical propulsion~~

Requires too much propellant

Artist's concepts

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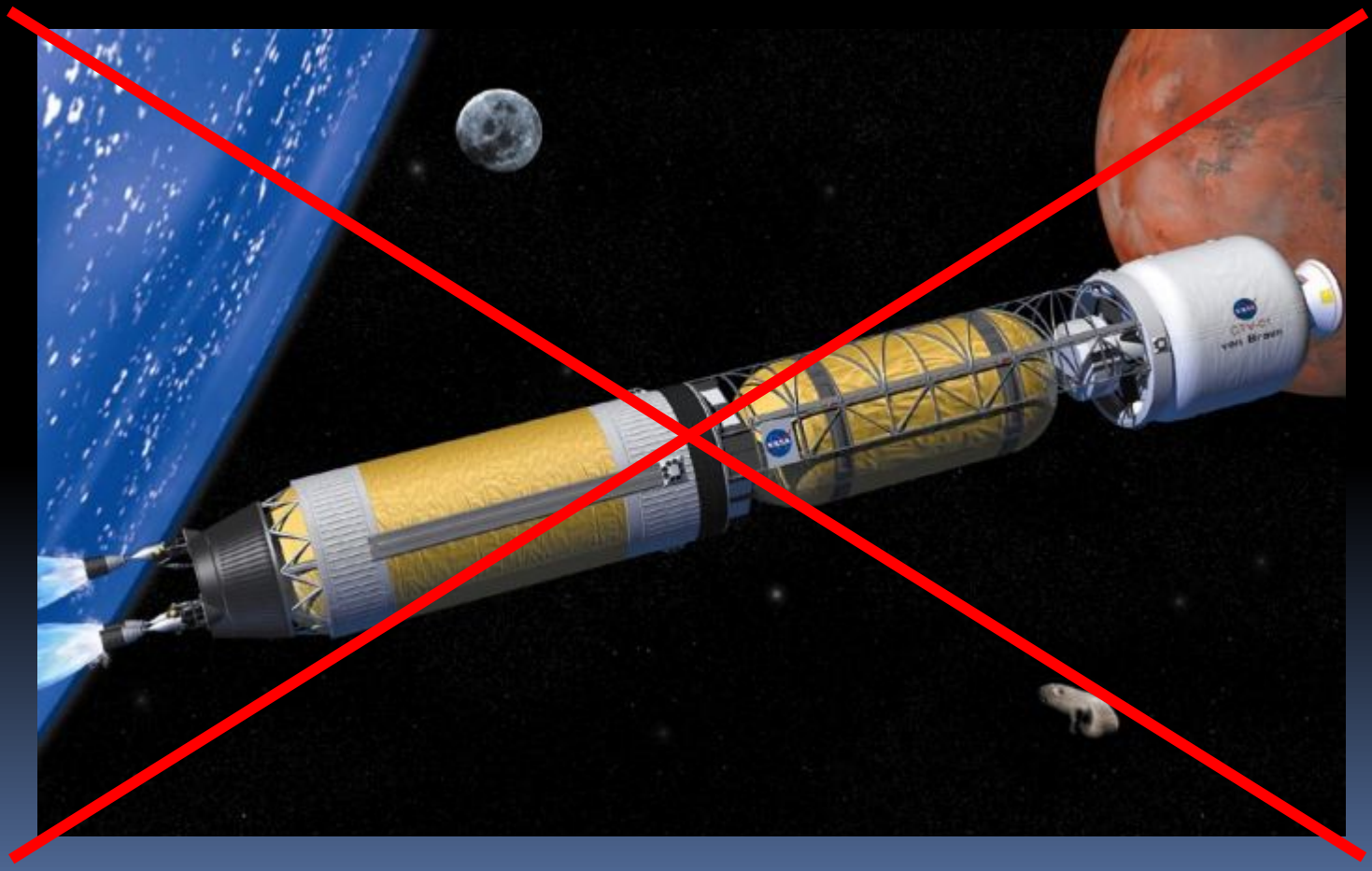
     - ~~Chemical propulsion~~
     - Nuclear propulsion
       - ~~Nuclear thermal~~



Still requires too much propellant

Artist's concepts

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1. ~~You can carry it with you~~
   - ~~Chemical propulsion~~
   - ~~Nuclear propulsion~~
     - ~~Nuclear thermal~~
     - ~~Nuclear electric~~

Too heavy
to go fast

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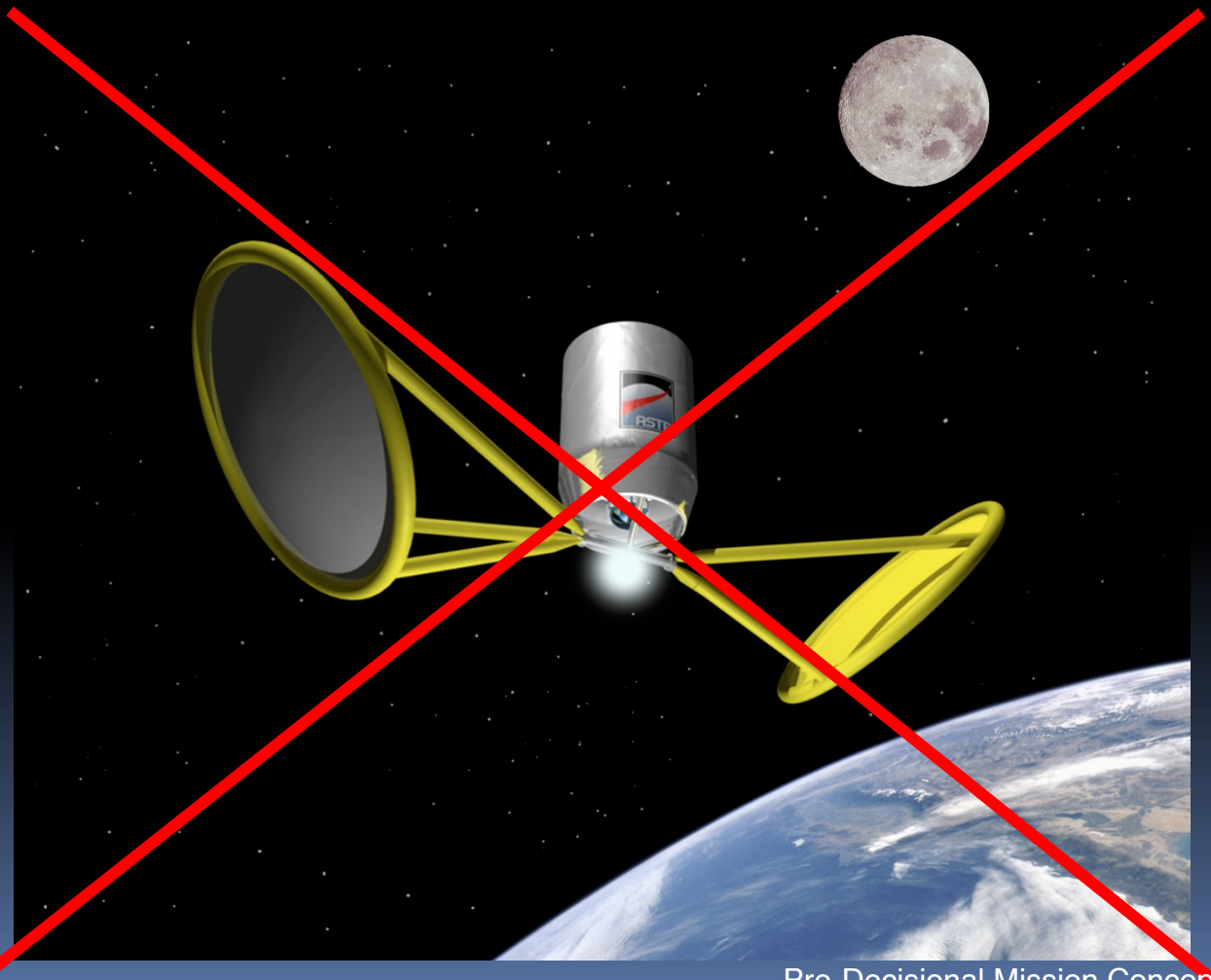
1. ~~You can carry it with you~~
   - ~~Chemical propulsion~~
   - ~~Nuclear propulsion~~
     - ~~Nuclear thermal~~
     - ~~Nuclear electric~~
2. You can collect energy transmitted to you
   - Solar
     - ~~Solar thermal~~



Requires too much propellant
Limited solar range

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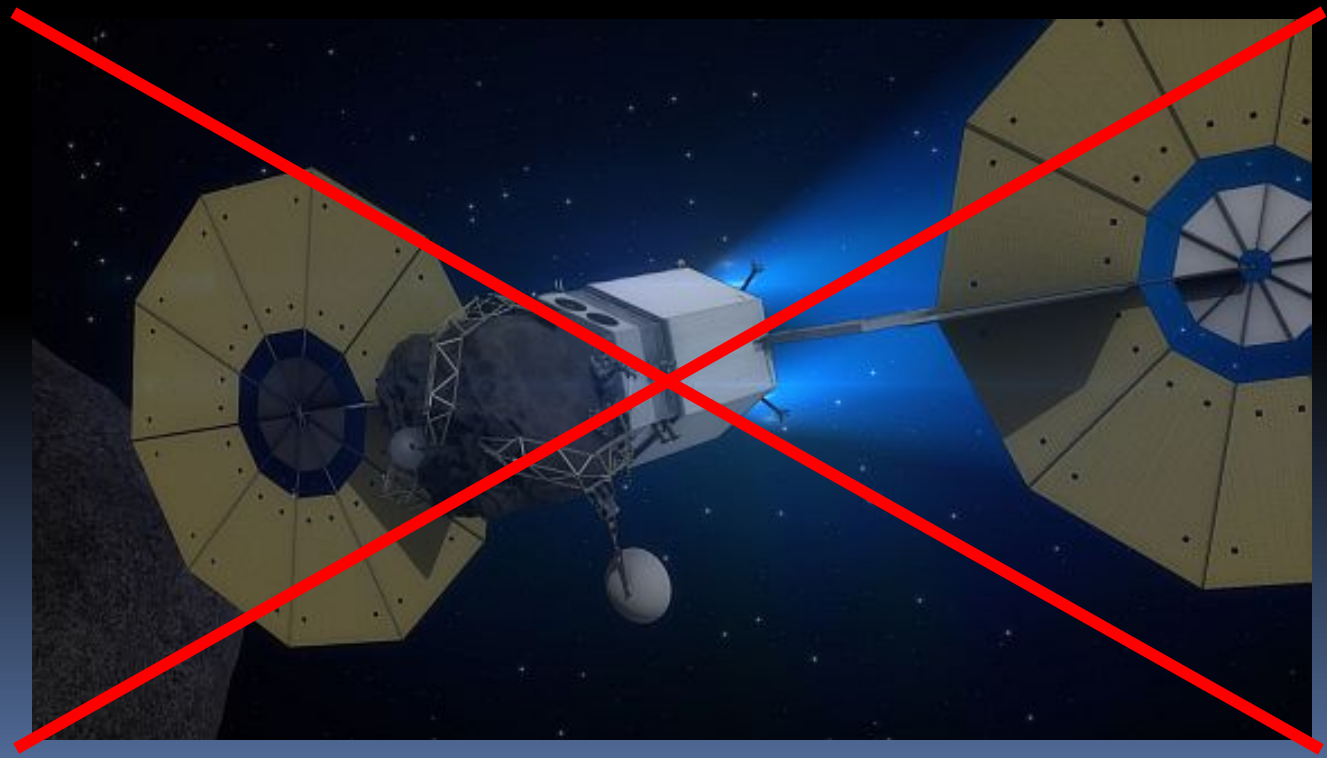
Still too much propellant
Limited solar range



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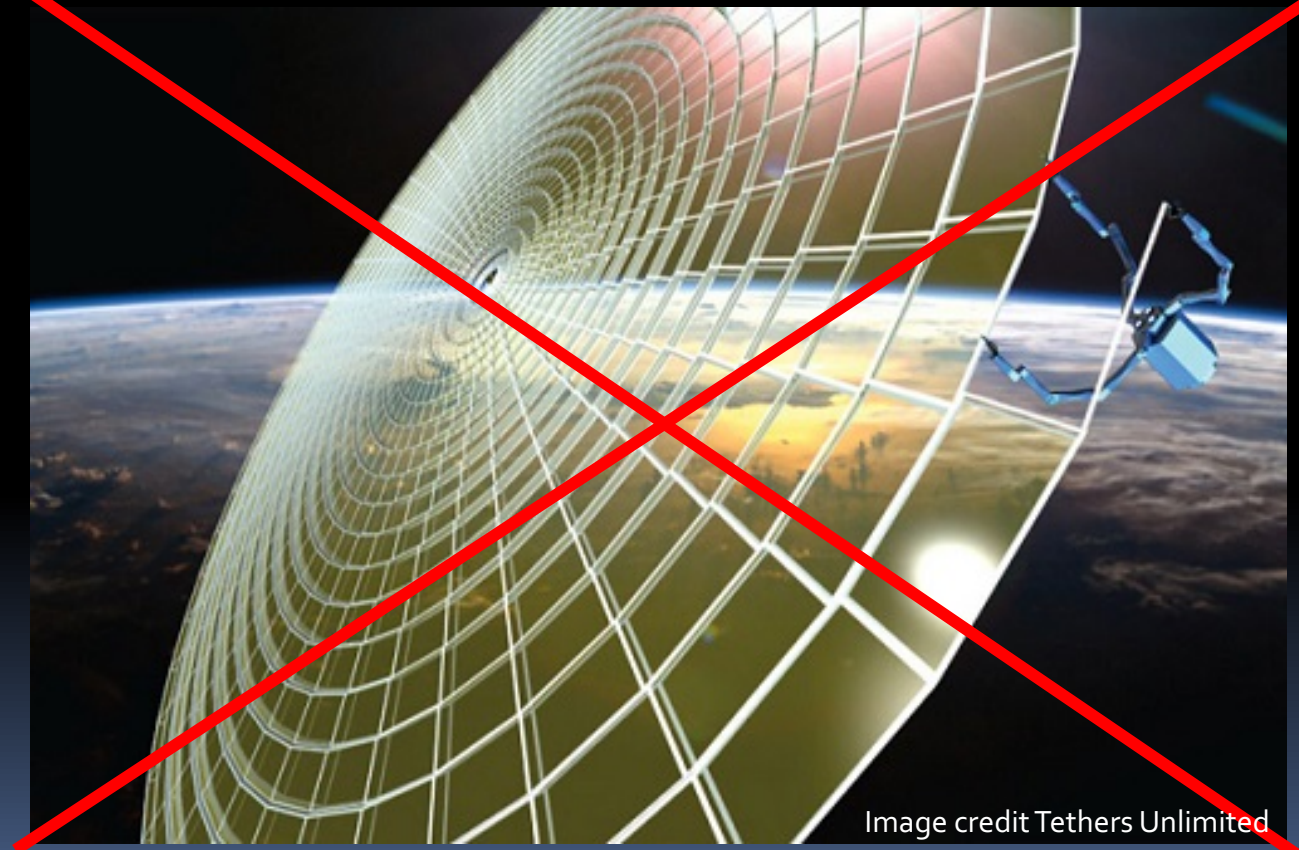
       - ~~Solar electric~~
     - ~~Microwave Sails~~

Wavelength too large → required aperture too large



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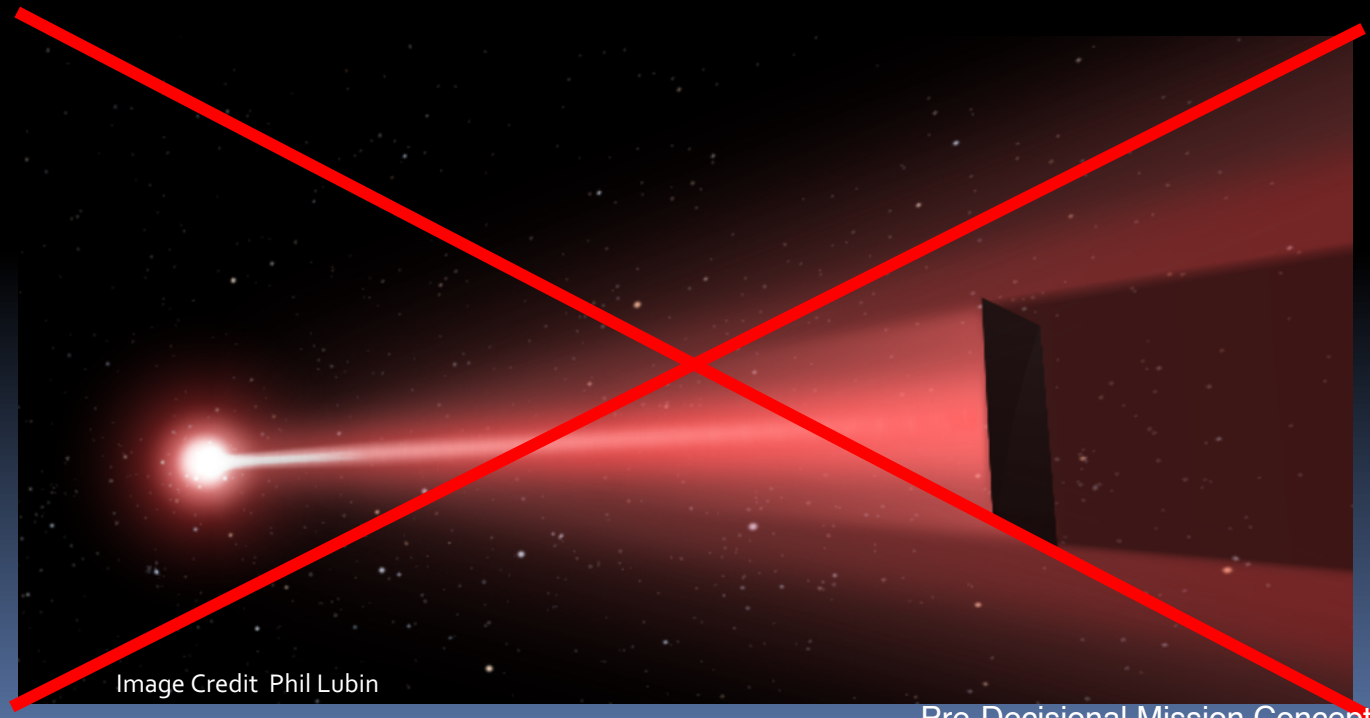
       - ~~Solar thermal~~
       - ~~Solar electric~~
     - ~~Microwave~~
     - Laser
       - ~~Laser sail~~

Thrust-to-power too low



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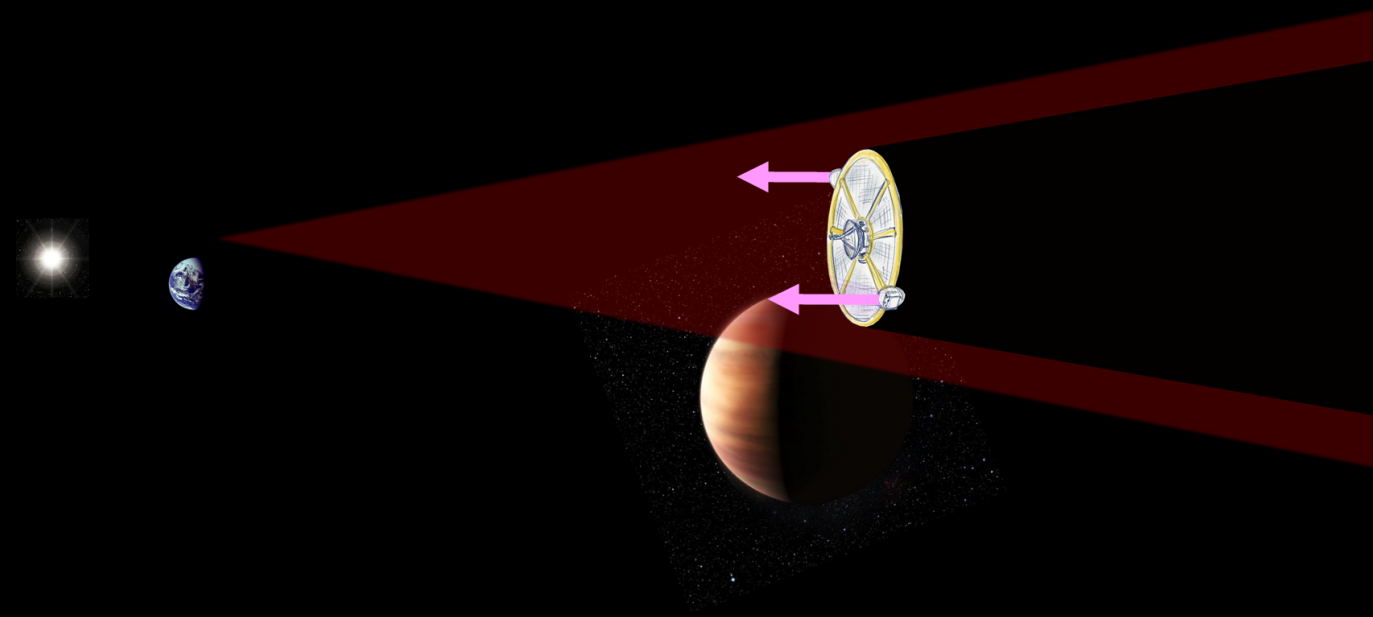
     - ~~Microwave~~
     - Laser
       - ~~Laser sail~~
       - Laser electric

Yes! Laser Electric Propulsion with Ultra-high Specific Ion Engines



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Pre-Decisional Mission Concept

Three Key Features of Our Proposed Architecture to Go Fast

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1

Kilometer-scale Laser

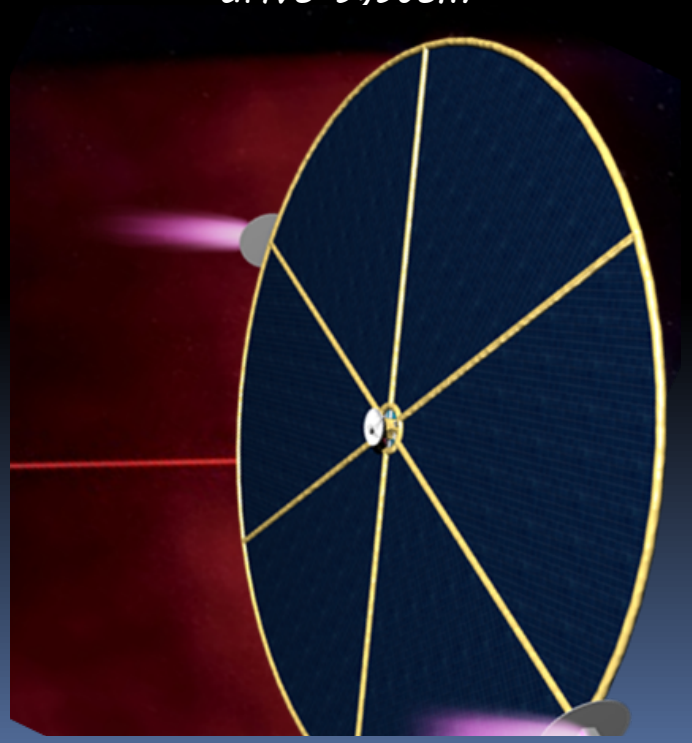
Don't carry the power source—laser beam power to the spacecraft

Image Credit Phil Lubin

2

Light-weight PV Collector

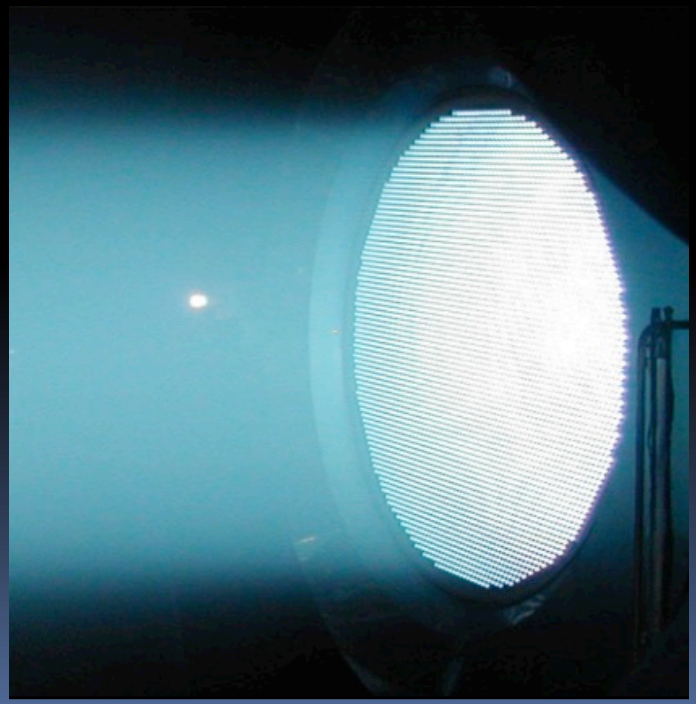
Collect the laser power and convert it to electricity to power the ion drive system



3

Ultra-high Isp Thruster

Increase the exhaust velocity by a factor of 10 over the best ion engines today



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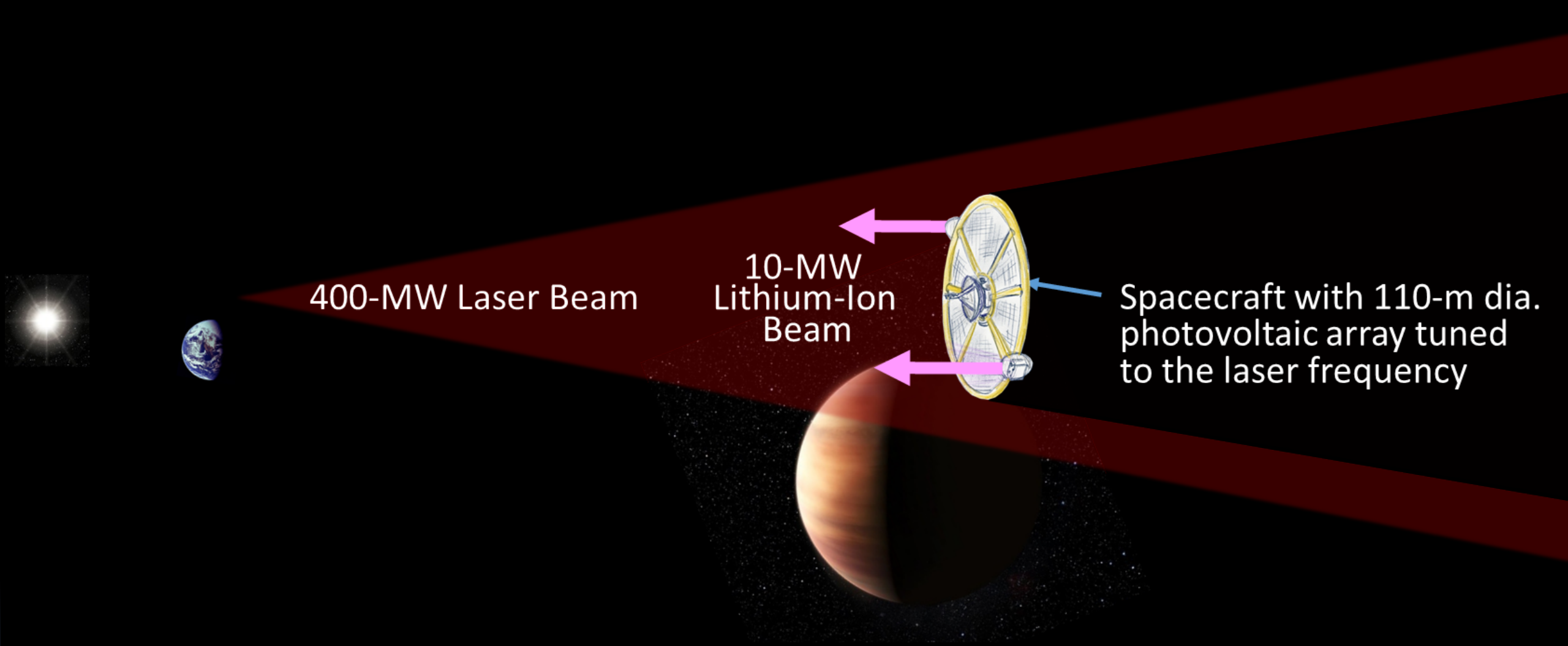
Pre-Decisional Mission Concept



A space-based laser beams power to a lithium-fueled, ultra-high specific impulse vehicle to enable rapid transportation throughout the solar system

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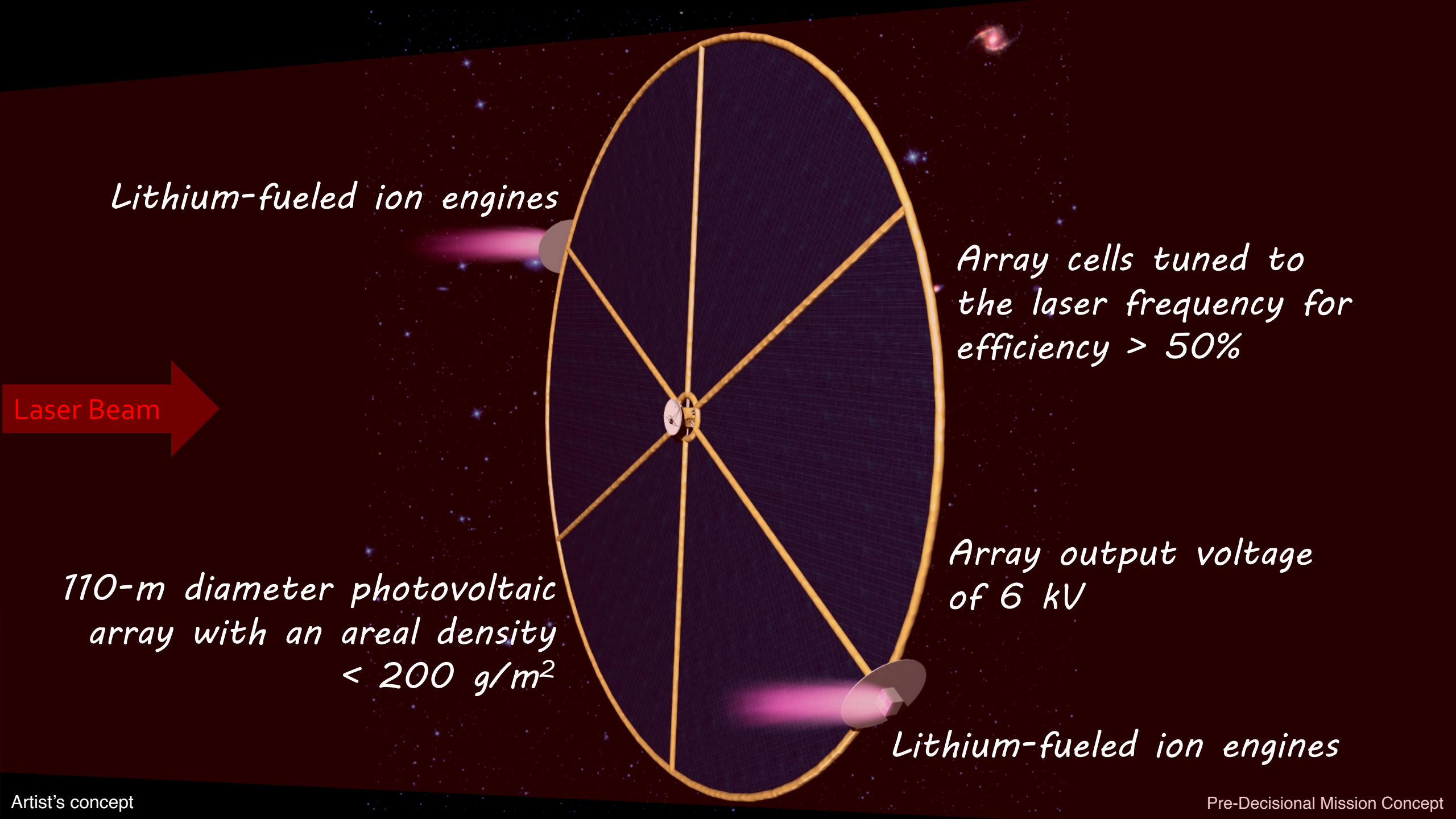

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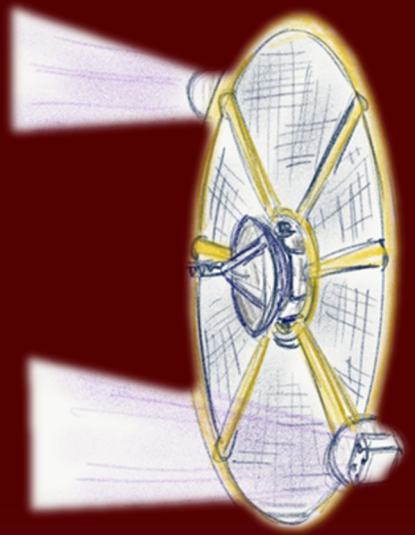
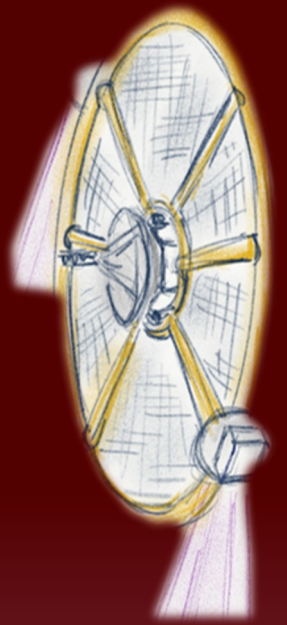
Pre-Decisional Mission Concept

Laser Beam



Thrusting along the laser beam



Thrusting normal to the laser beam

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Four Technology Wavefronts

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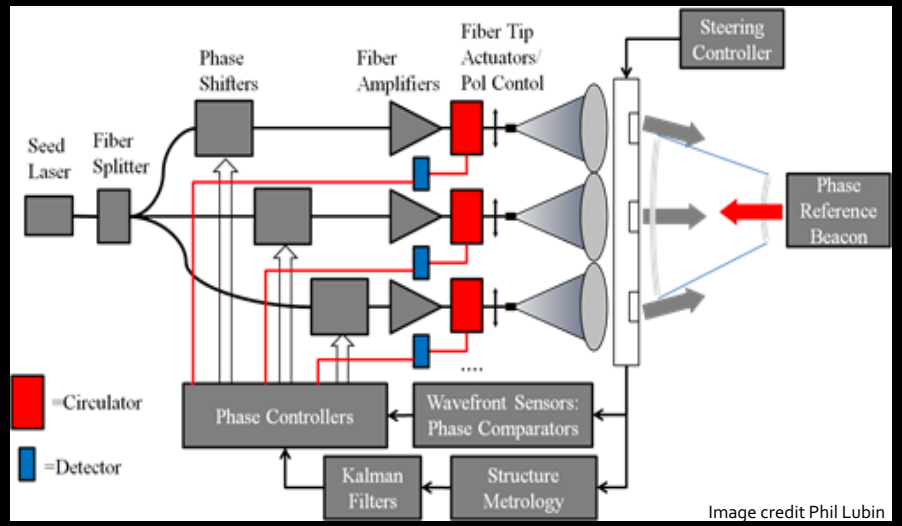
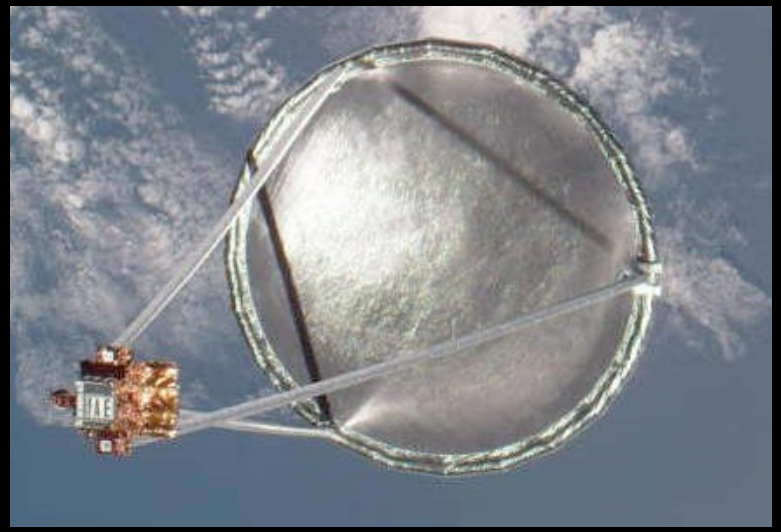
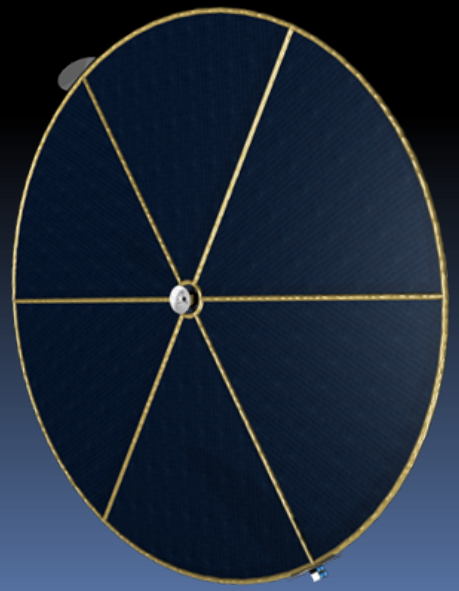
1. Large Phased-Array Laser Technology
   - Space-based
   - km-scale
   - 100's MW



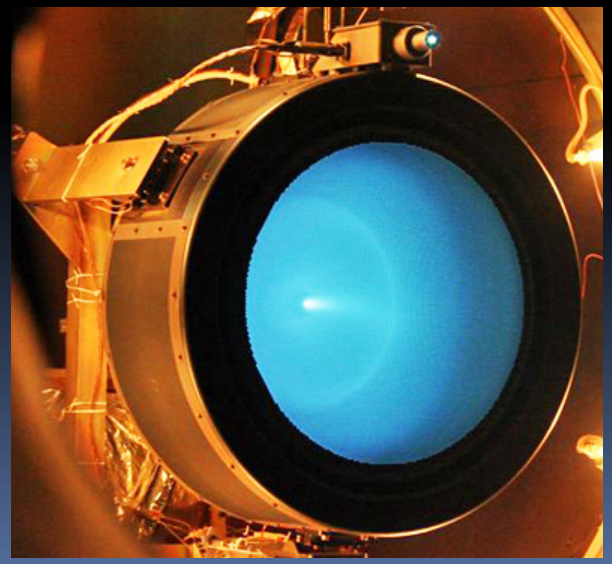
2. Large Deployable Structures
   - 100-m
   - 200 g/m^2



3. Advanced Photovoltaics
   - > 50% at the laser frequency
   - Thin-film
   - 6-kV output voltage



4. Ultra-High Specific Impulsion Ion Thrusters
   - 50,000 s
   - 95% efficiency
   - Direct-drive



1 Laser Scaling

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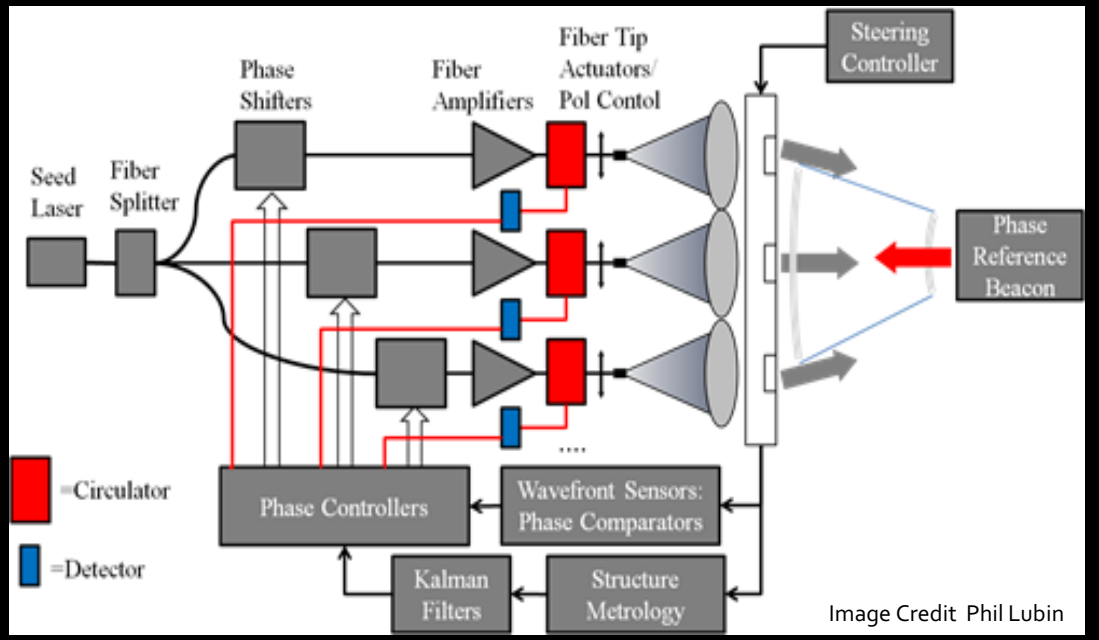
- Diffraction-limited optics → very large aperture, km-scale laser
  - Phase-array laser, only known way to get a km-scale laser due to optics cost and practicality
  - Diffraction-limited performance requires a densely packed array
  - km-scale, densely packed, phased array laser → very high powers, ~100 MW
- Popular Mechanics
  - Humanity's Biggest Machines Will Be Built in Space, By Avery Thompson, Feb 16, 2018
  - "A mile-wide satellite might sound impossible, but that's exactly where the space industry is headed."



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Increase Power Density by 100X Across the Solar System

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High-power, space-based laser

- Phased array
- Kilometer-scale aperture
- 100's of megawatts

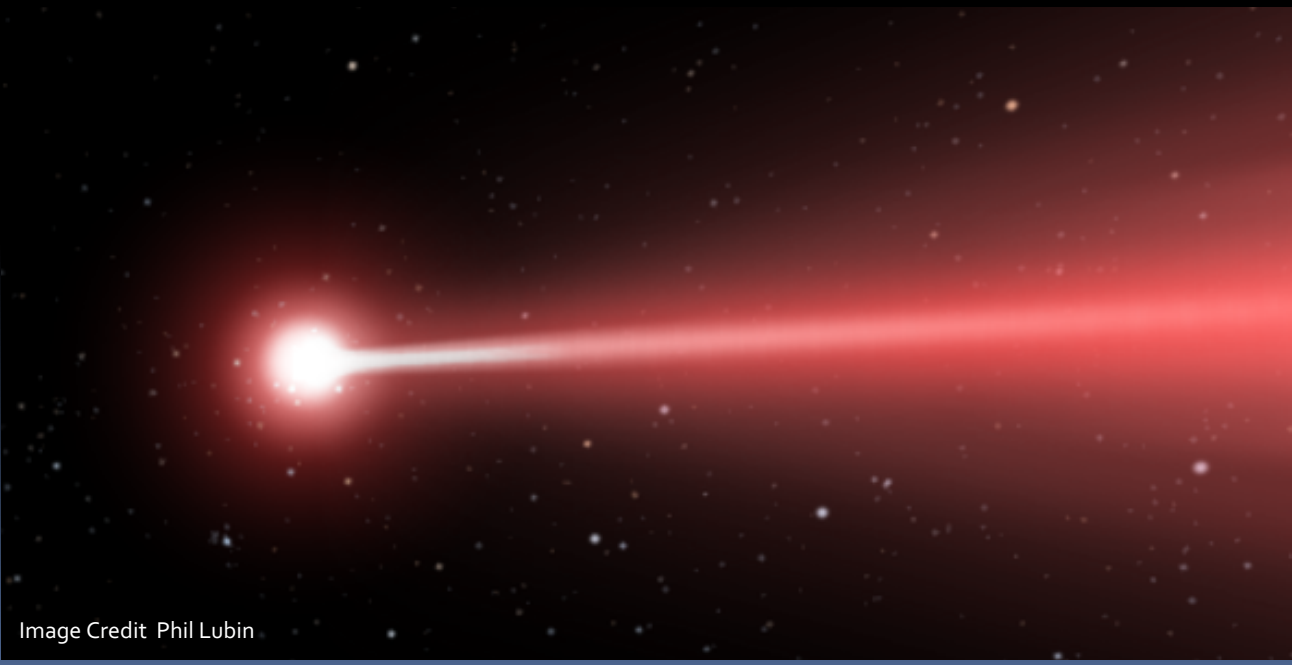
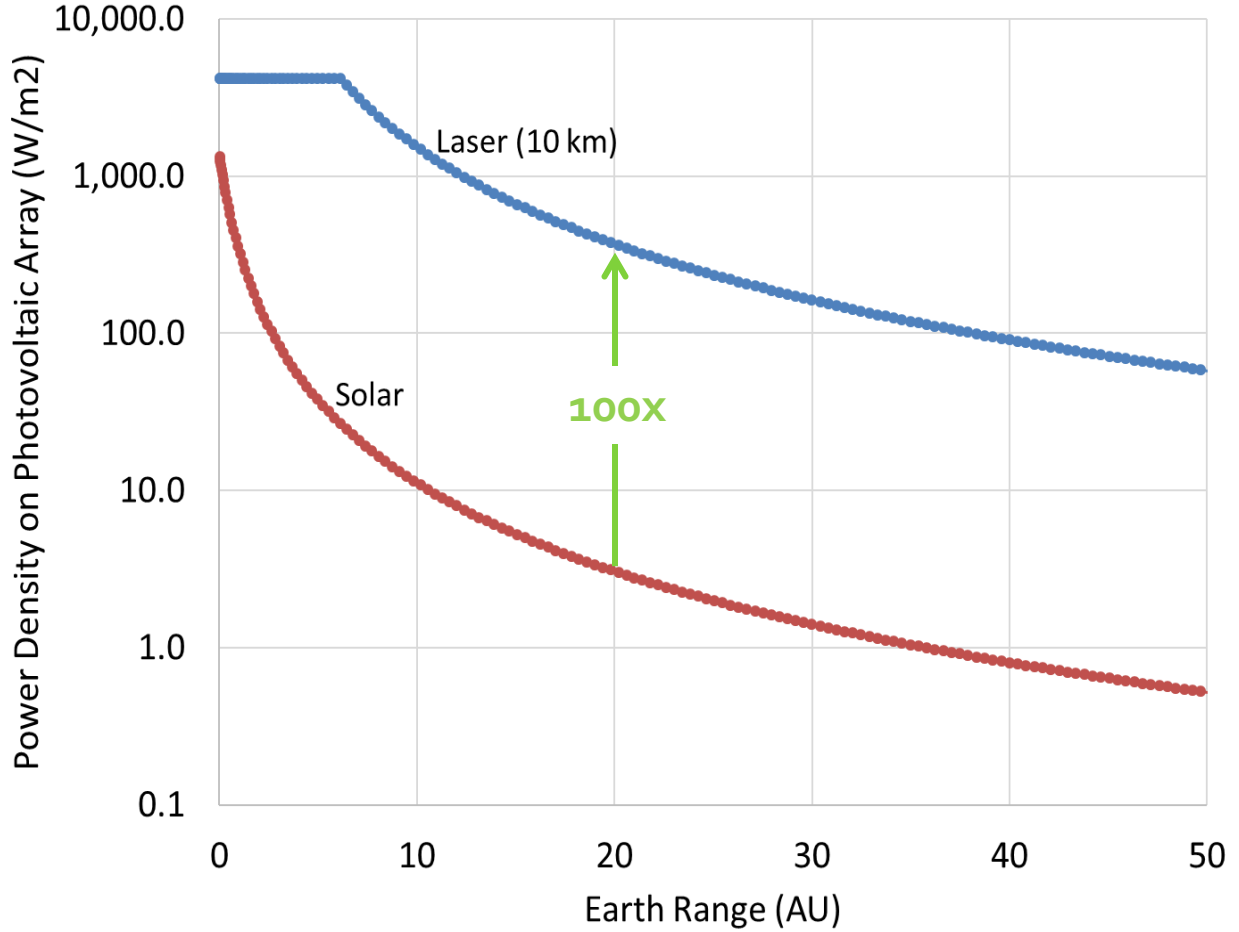


Image Credit Phil Lubin

Beam Power Across the Solar System



Pre-Decisional Mission Concept

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Trade Laser Aperture Size, Power, and Wavelength

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Option 1:

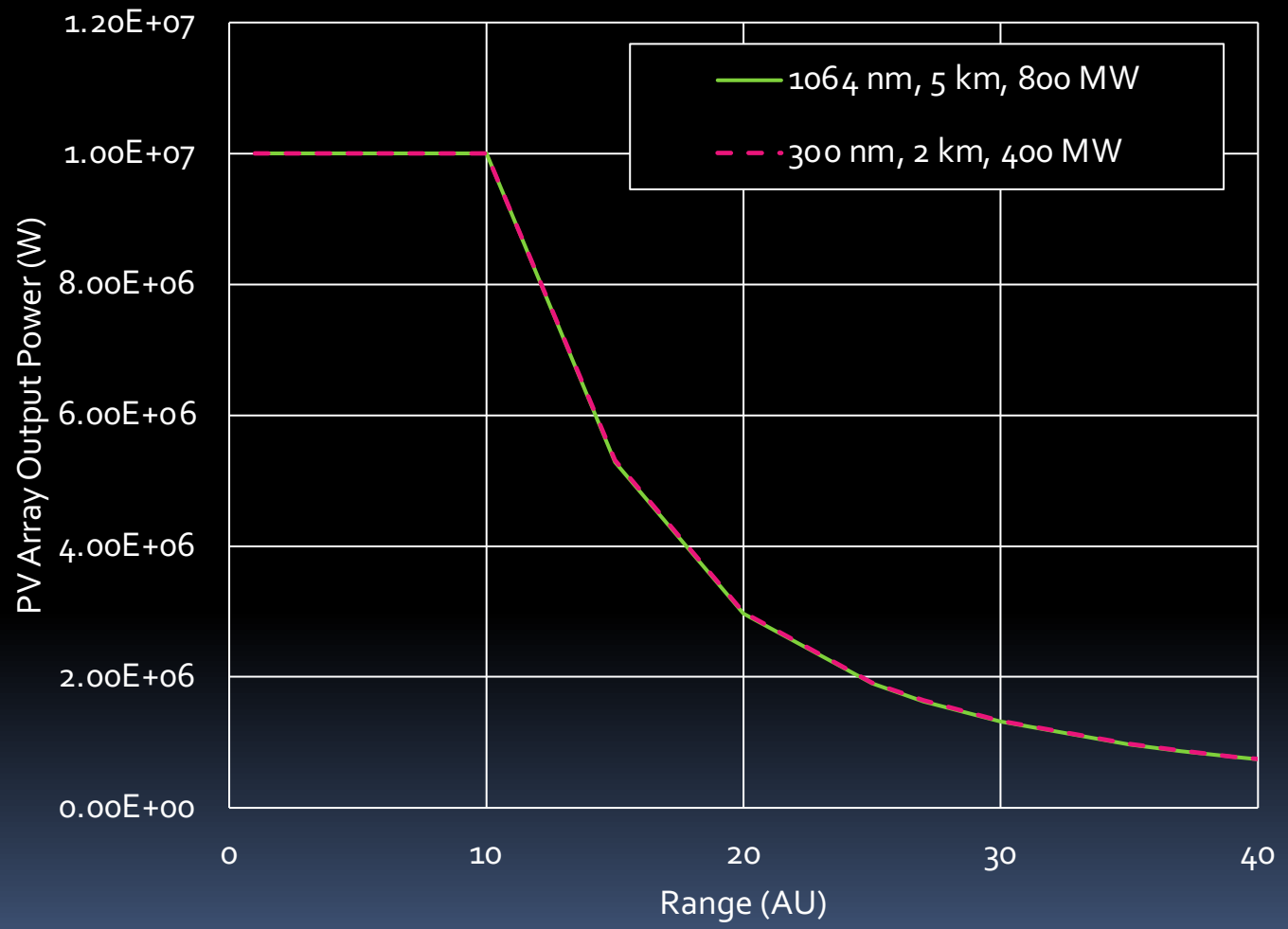
- Laser Wave Length 1064 nm
- Laser Aperture Dia 5000 m
- Laser Output Power 800 MW

Option 2:

- Laser Wave Length 300 nm
- Laser Aperture Dia 2000 m
- Laser Output Power 400 MW

PV Array:

- PV Array Diameter 110 m
- PV Areal Density 200 g/m^2
- PV Cell Efficiency 0.5
- Mass of PV Array 1.90E+03 kg
- Max Output Power 1.00E+07 W



System Provides Fantastic Power Levels Across the Solar System

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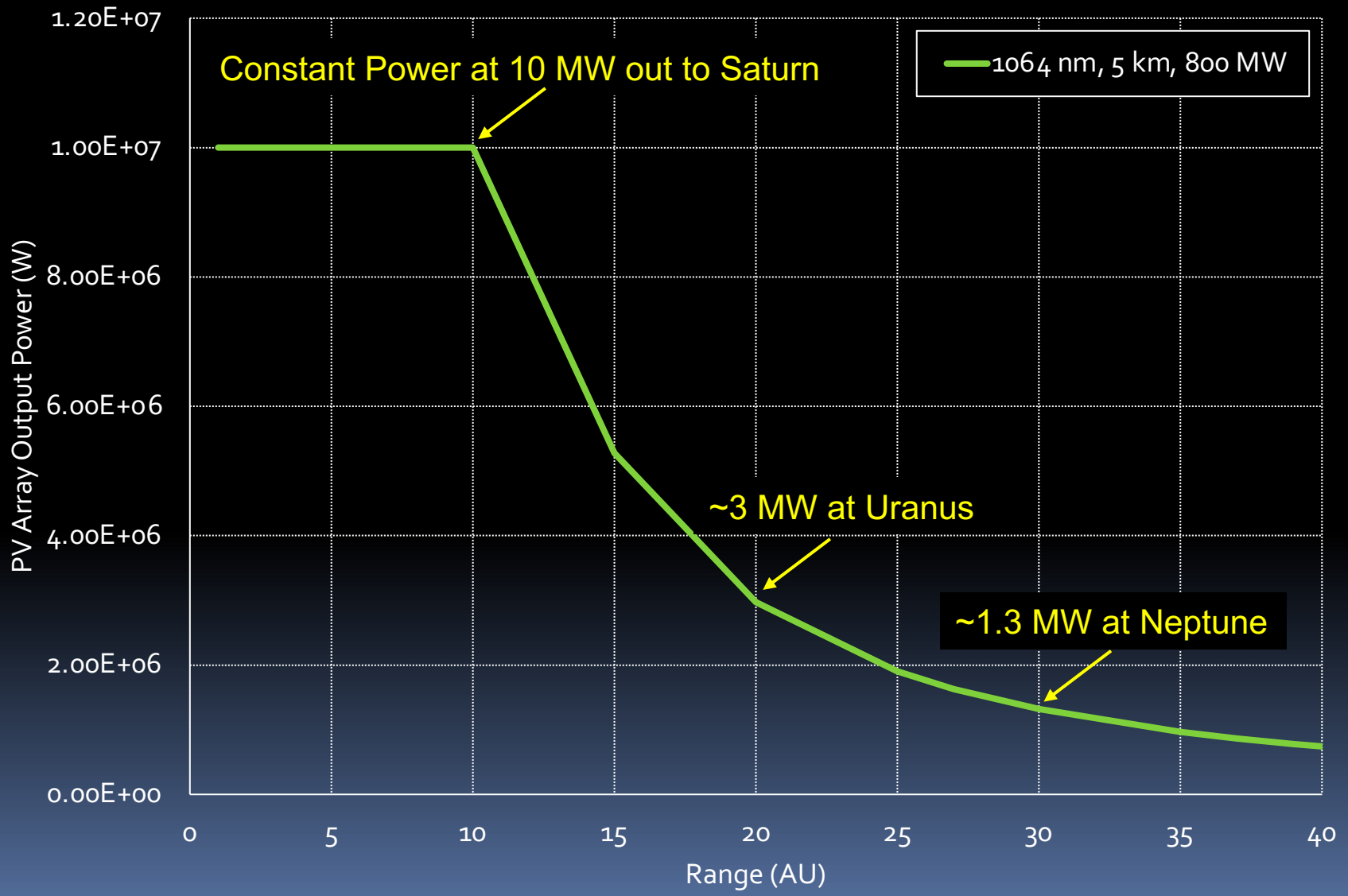

2 Photovoltaic Array Scaling

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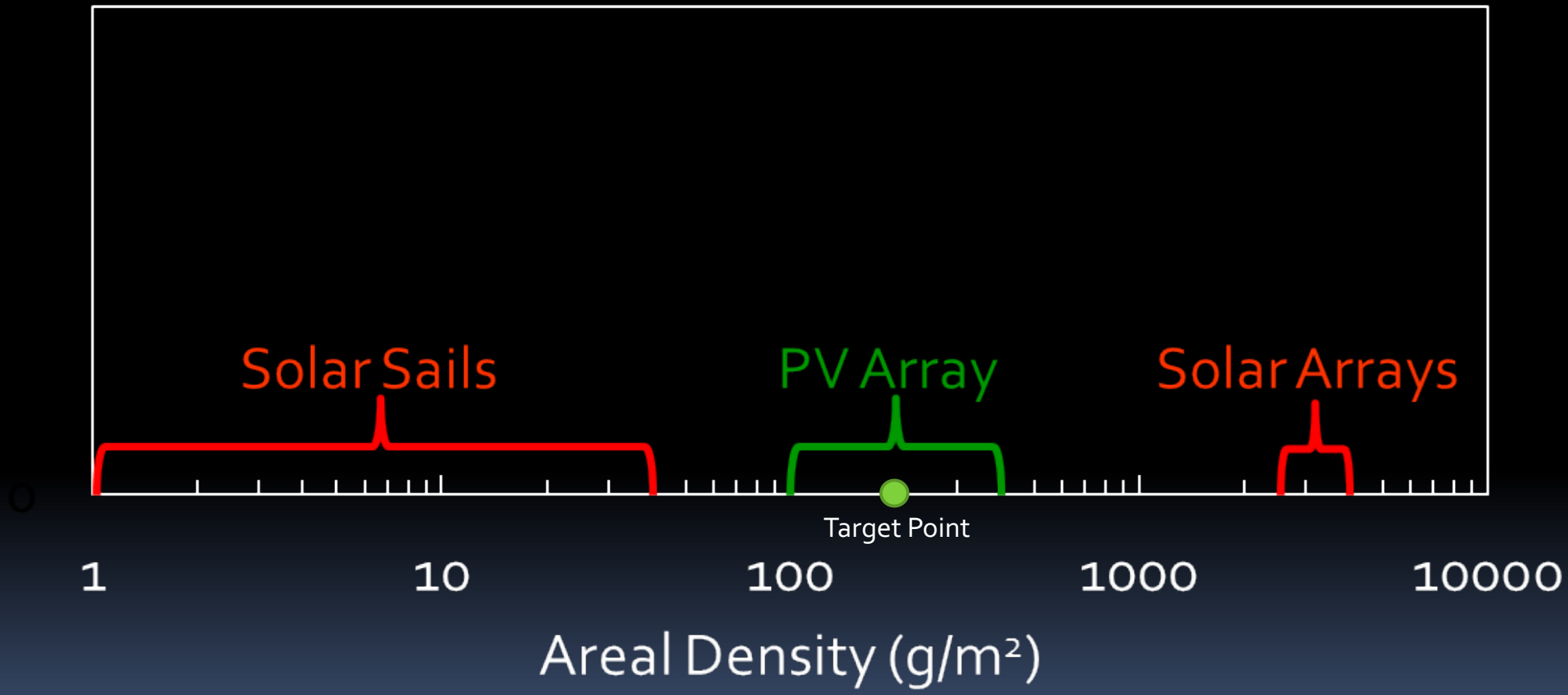
Areal Density is the Key



Provides Much Higher Specific Power (W/kg) than Other Approaches

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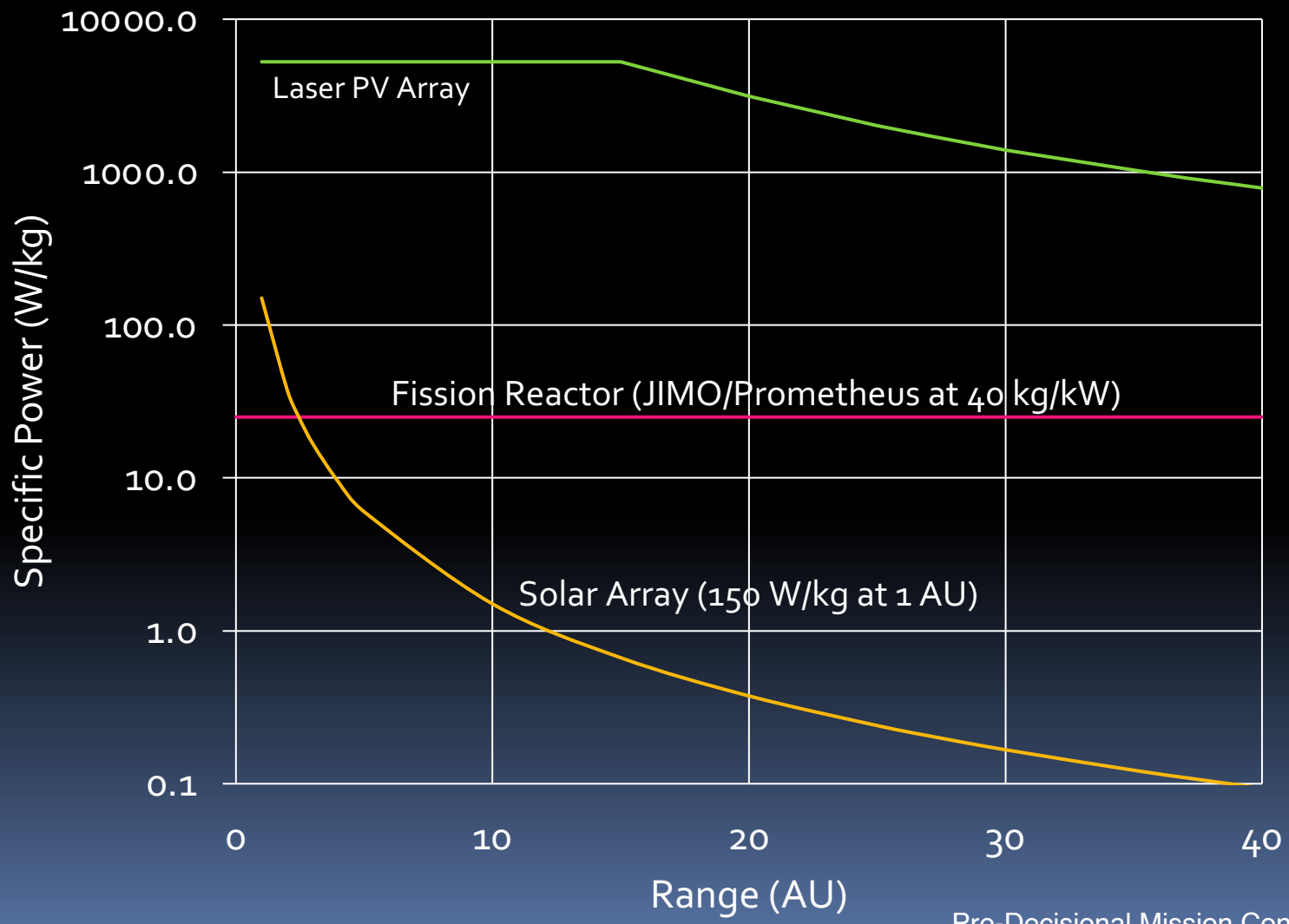
- Specific Power is the key to high performance
- Laser-driven PV array has significantly greater specific power throughout the solar system



PV Array Scaling has Broad Optimum Around 110-m dia.

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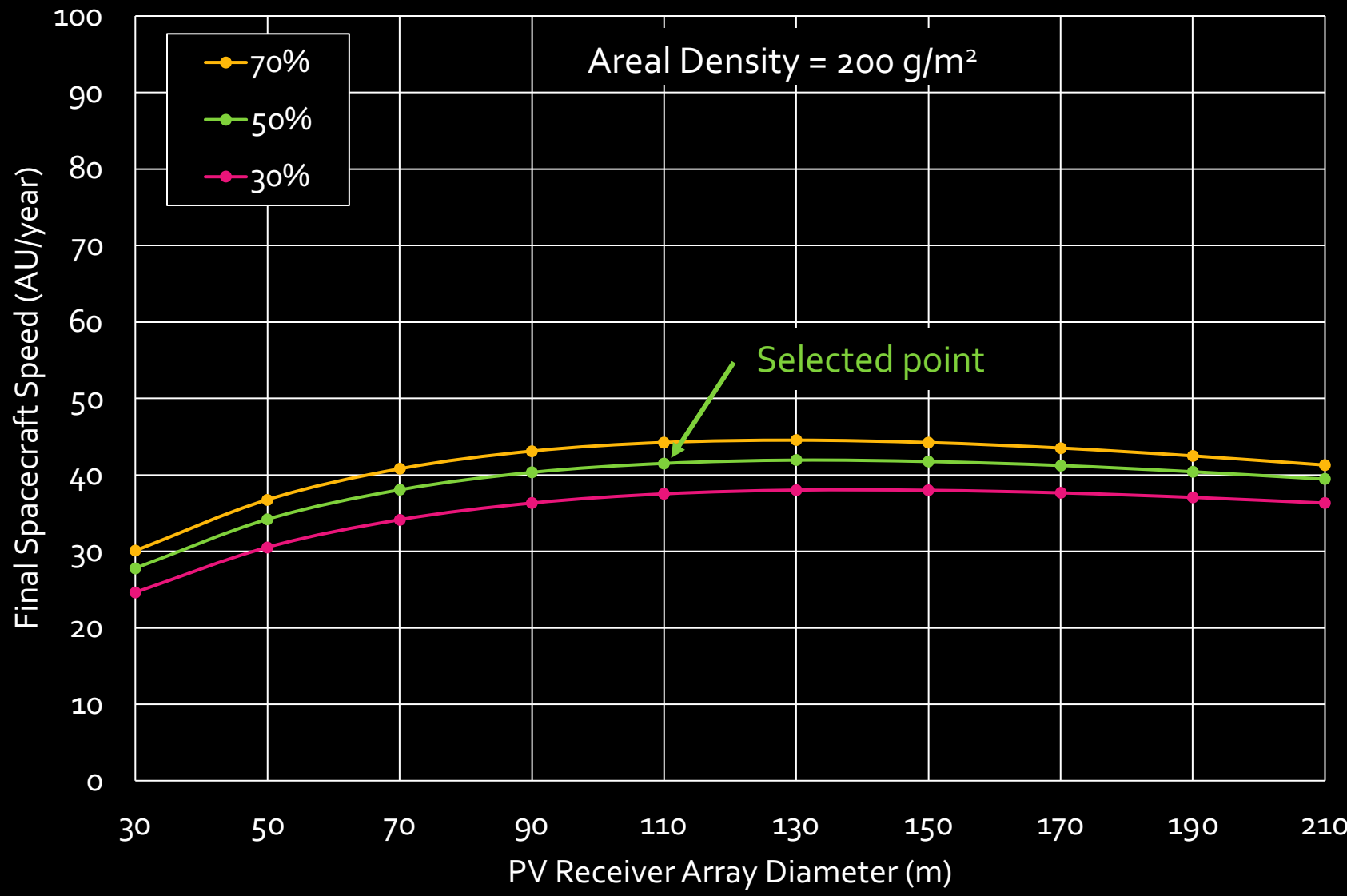
- Want 40 AU/year (190 km/s)
- Select 110-m diameter at 50% PV cell efficiency



Laser Spot Size is Always Bigger then the PV Array

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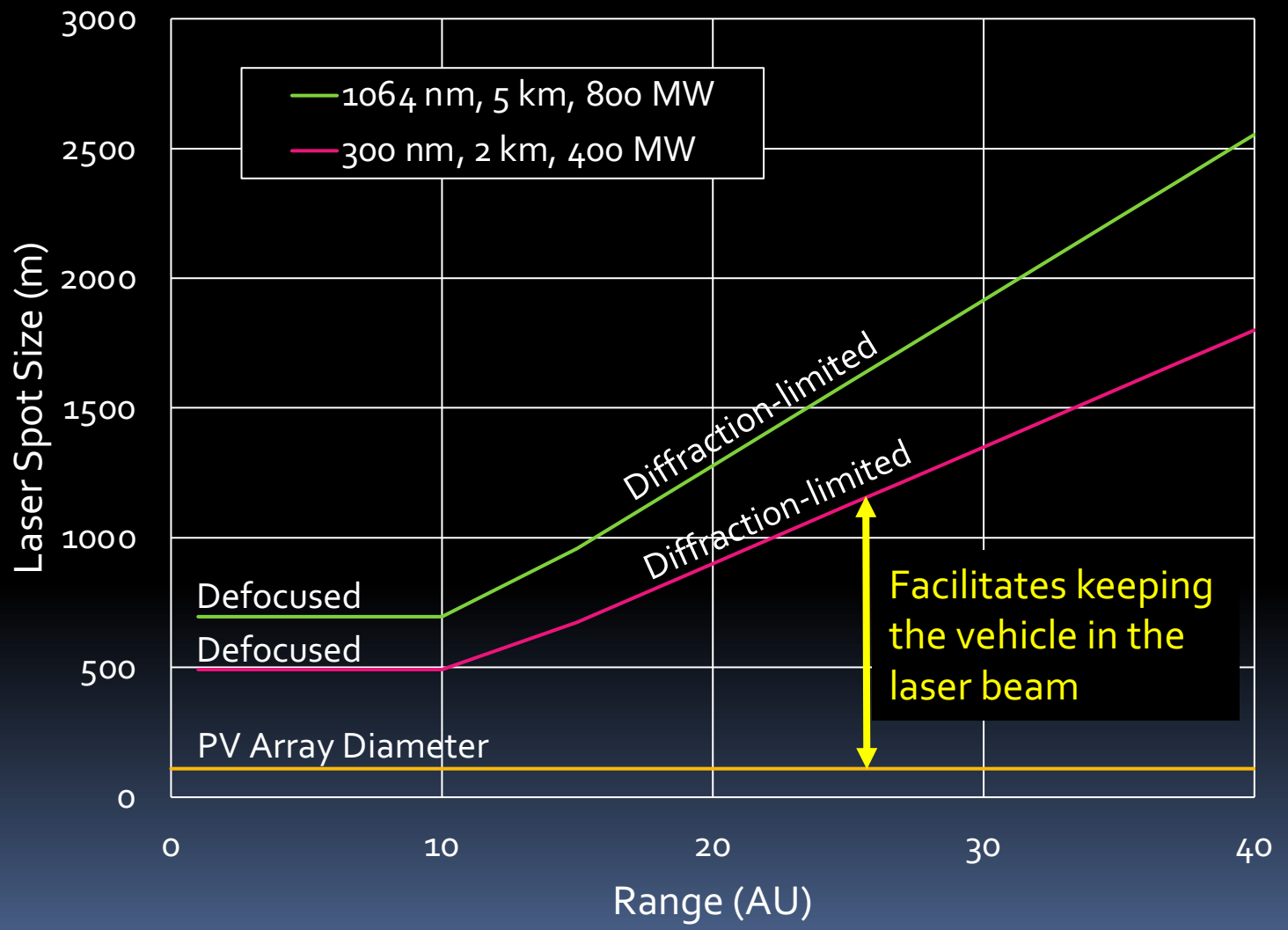
- km-scale laser aperture required to beam power across tens' of AU
- Densely-packed phased-array laser results in very high power, 100's of MW
- Minimize size of the EP vehicle
- ➢ Don't size the EP vehicle to use all the available power (just like outbound SEP missions!)



3 Electric Propulsion System Scaling: *Isp*

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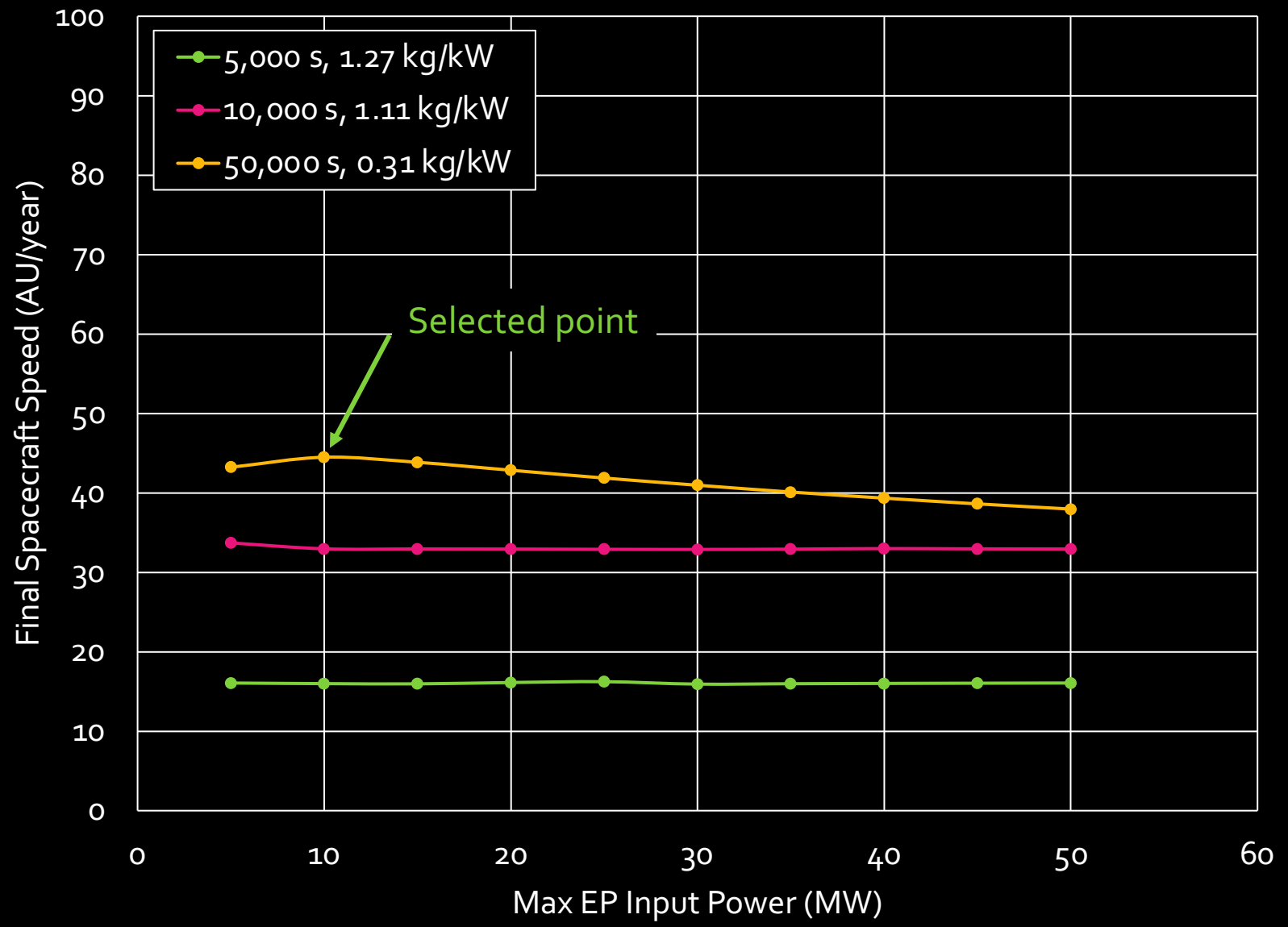
- *Specific Impulses of order 50,000 s are required to achieve 40 AU/year*
- *Specific Masses are higher at lower Specific Impulses*
- *Need Max EP Power of about 10 MW*



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Electric Propulsion Specific Mass

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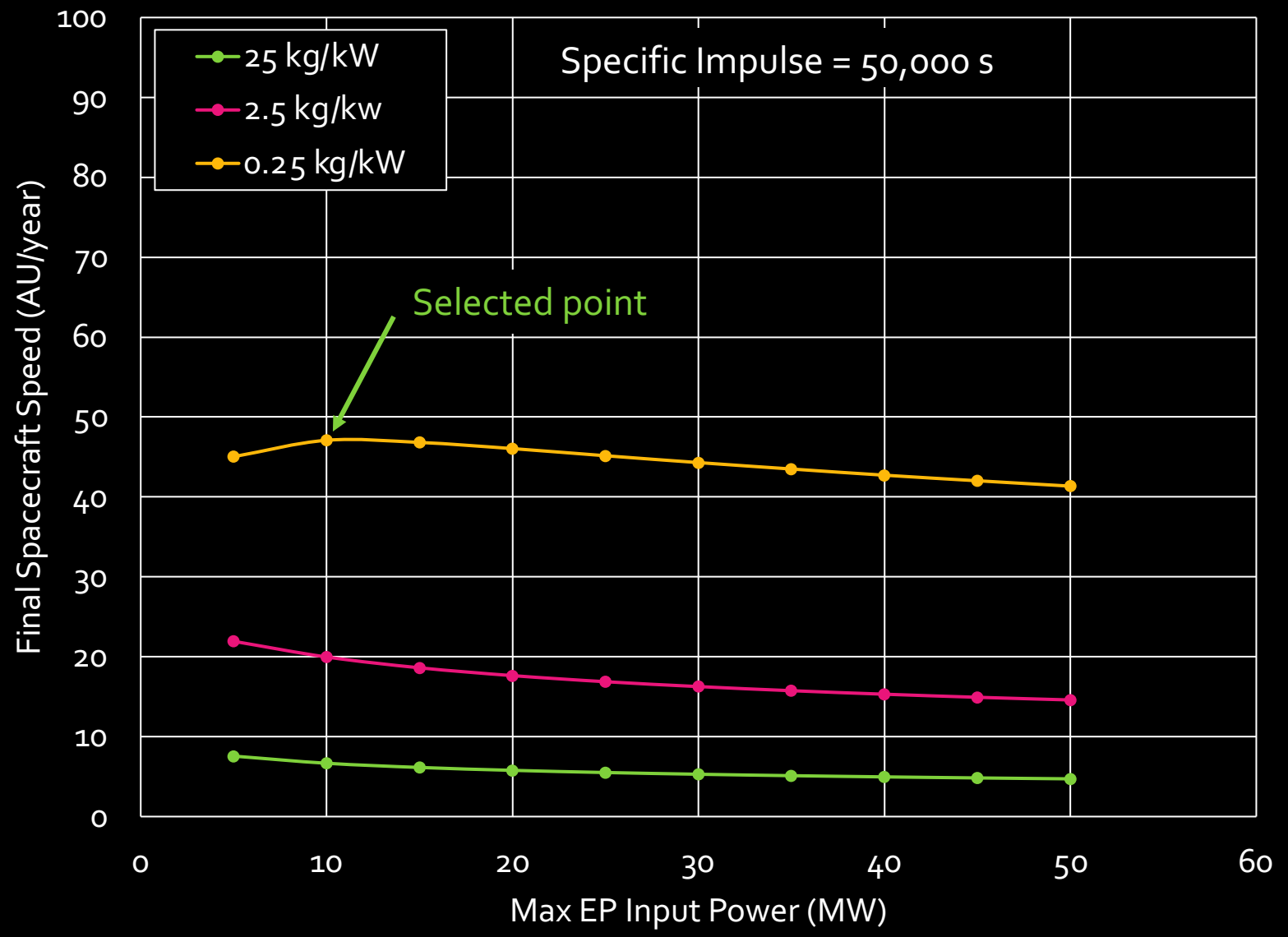
Need specific masses of order 0.25 kg/kW to achieve > 40 AU/year



Lithium-fueled Ion Thruster

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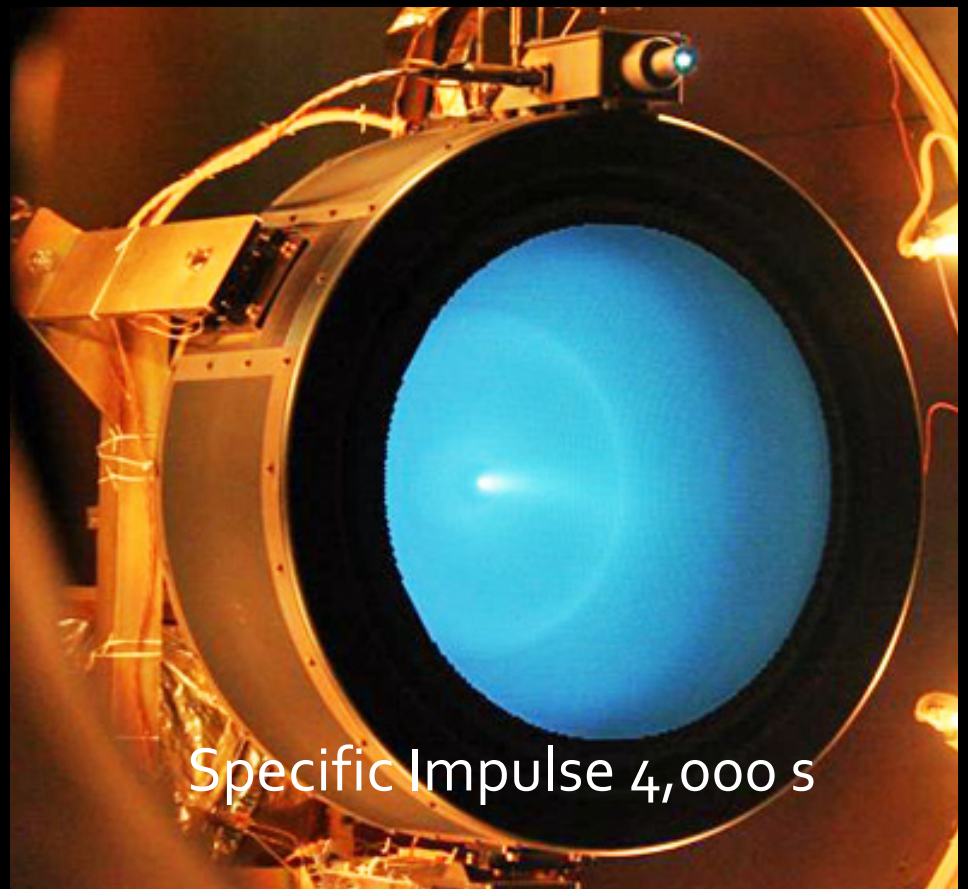
Xenon-fueled

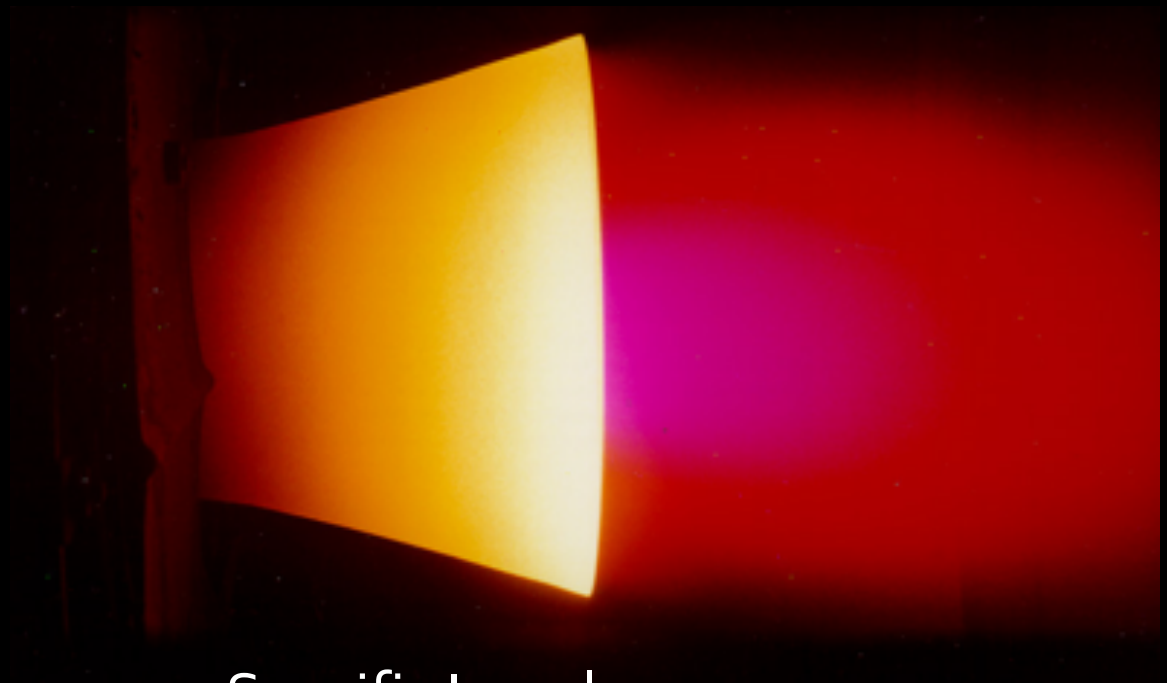
Today's ion engines have 10X the exhaust velocity of the best chemical rockets



Specific Impulse 4,000 s

Lithium-fueled

Our ion engines will have 10X the exhaust velocity of the best ion thrusters



Specific Impulse > 40,000 s

What Might this Architecture Be Able to Do?

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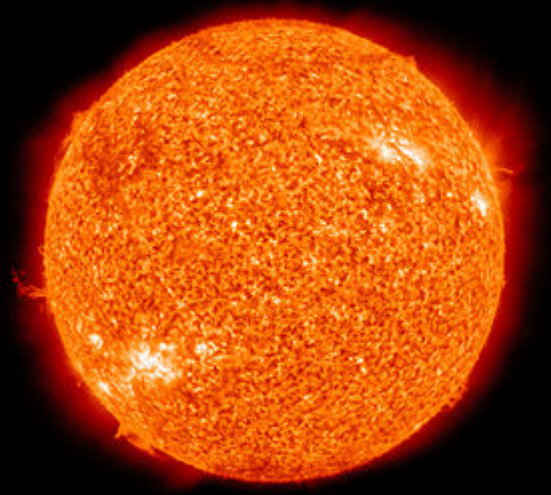
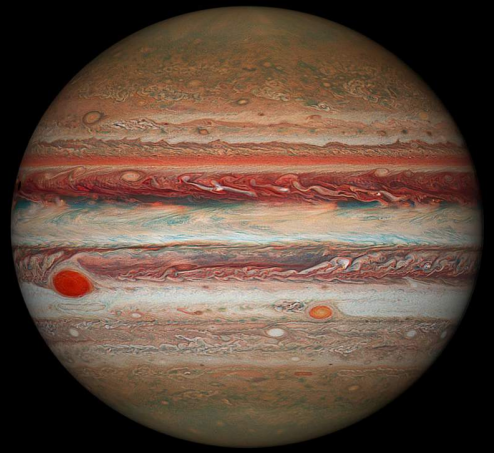
Solar Gravity Lens Mission



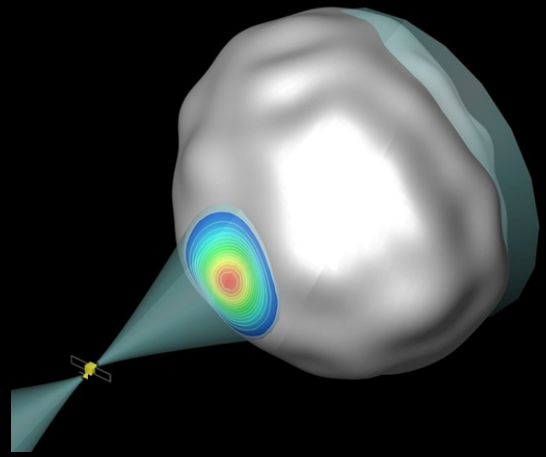
Pluto Orbiter Mission

Image by *New Horizons*

Human Missions to Jupiter



Planetary Defense—Ion Beam Deflection



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